The NOEMA Front-End

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Abstract— **The IRAM Plateau de Bure Interferometer (PdBI) is being upgraded to a new powerful millimeter-wave radio astronomy facility called the NOrthern Extended Millimeter Array (NOEMA) which will double the number of 15-m diameter antennas from six to 12. All antennas will be equipped with a new generation of dual-polarization Front-End based on quadri-band Sideband Separating (2SB) Superconductor-Insulator-Superconductor (SIS) mixers delivering four ~7.6 GHz wide Intermediate Frequency (IF) outputs per band, thus enabling to increase the total IF processed bandwidth of the interferometer from 8 GHz to ~31 GHz.**

The NOEMA Antenna 7 has recently been completed and the first NOEMA receiver has been successfully developed and installed in it. For the coming years, our goal is to upgrade all the Front-Ends currently installed on the six existing PdBI antennas to the new NOEMA standard and to build four additional ones (three plus one spare) for the new NOEMA antennas.

In this paper, we describe the design, fabrication and assembly of the Front-End we have developed for NOEMA Antenna 7. Such Front-End has state-of-the-art performance and sets a new standard in the post-ALMA generation technology.

I. Introduction

The NOEMA Front-End specification required re-designing the existing PdBI Front-Ends, which have been in continuous operation since their installation in 2006. In particular, the backshort tuned Single Side Band (SSB) SIS mixers delivering 4 GHz IF bandwidth per polarization channel, currently adopted for PdBI Bands 1, 2, and 3, are upgraded to the NOEMA 2SB mixer configuration providing two ~7.6 GHz wide IF bands (LSB and USB) per polarization channel. This will increase the total IF band delivered to the correlator from 2 x 4 GHz (8 GHz) to 4 x ~7.6 GHz (~31 GHz). Also, the four RF bands of the NOEMA receivers will be larger than the ones of the current receiver generation. In particular, the Band 1 lower frequency edge is extended to 72 GHz, thus allowing covering important molecular lines not yet accessible to ALMA. Table 1 provides the main specifications for the different bands of the PdBI and of the NOEMA Front-Ends.

II. NOEMA Front-End: System overview

The NOEMA Front-End system design and architecture were described in a previous work [1]. The instrument features many novelties and improvements, the most important ones being the following: an improved thermalization of the cryogenic stages leading to quicker warm-up/cooling down cycles, improved optics, new mixers, new IF sections at cryogenic and room temperatures, new optical-fiber laser rack for the IF signals, new local oscillator systems, improved calibration loads, new control electronics. Here, we report on the development of the key components of such receiver.

The cryogenic system adopted for the NOEMA Front-End is the same as the one currently adopted at PdBI, which is based on a closed-cycle cryocooler (Sumitomo model SRDK3ST) with three cryogenic stages at 80 K, 15 K and 4 K. The NOEMA cryostat vacuum enclosure and inner IR screens at 80 K and 15 K have the same size as those of the PdBI receiver.

The electronically tuned local oscillator system employed to pump the SIS mixers is described in a separate article [2], presented at this symposium, and will not be discussed here.

It was decided to keep the Band 4 receiver module currently used in the PdBI cryostat, which delivers 4 GHz IF band per polarization channel. This is based on an ALMA Band 7 2SB SIS mixer with one IF sideband internally terminated into a matched load. It is foreseen to upgrade the Band 4 receiver in the near future.

	Current PdBI Front-End			NOEMA Front-End		
Band	**RF [GHz]**	**IF [GHz]**	**Mixer scheme**	**RF [GHz]**	**IF [GHz]**	**Mixer scheme**
1	83-116	4-8	SSB	72-116	3.872-11.616	2SB
2	129-174	4-8	SSB	127-179	3.872-11.616	2SB
3	200-268	4-8	SSB	200-276	3.872-11.616	2SB
4	277-371	4-8	2SB	275-373	3.872-11.616	2SB

Tab 1 Bands definition and SIS mixer technologies of the current PdBI receivers and of the NOEMA receivers under development.

A. Optics

1) *Vacuum windows and IR filters:* The RF signals of the four bands enter the Front-End through four independent HDPE vacuum windows and PTFE Infrared filters of improved design (Fig. 1). A broadband matching layer with low reflection coefficient is obtained for all bands with triangular grooves machined into each dielectric surface with angle $\alpha=20^0$ and appropriate pitch (P) and height (H) that avoid the appearance of spurious modes. Corrugations on one face are

perpendicular to those on the other face to avoid artificial birefringence.

Fig. 1 *Left:* HDPE vacuum window showing the triangular grooves on one of the surfaces. *Right:* Geometry of the corrugations.

2) *Cryogenic optics modules:* Improved cryogenic optics modules were designed, fabricated and tested for Bands 1, 2 and 3 (Fig. 2, top panel) in order to cover the large NOEMA RF bandwidths. All modules share the same design philosophy, similar to that adopted in the existing PdBI receivers, where two ellipsoidal mirrors thermalized at 15 K re-image the antenna sub-reflector into the apertures of the two independent single-polarization feed-horns. The modules are more lightweight and compact than the previous ones. A polarization splitting wire-grid and the feed-horns, attached to the main frame of the module, are maintained at 4 K. Fiberglass tabs are used to thermally split the 15 K and the 4 K stages. The optics modules were tested at room temperature using the IRAM mm-wave antenna range as well as at their operating temperature inside the fully assembled receiver. They proved to work well, according to the prescribed specifications. The co- and cross-pol beam-patterns of each polarization channel were measured near the central RF frequency and at the band edges. Co-polar beam-patterns of the modules measured at room temperature are shown on Fig. 2, bottom panel. The sidelobe and the cross-polarization levels are less than -20 dB for all bands.

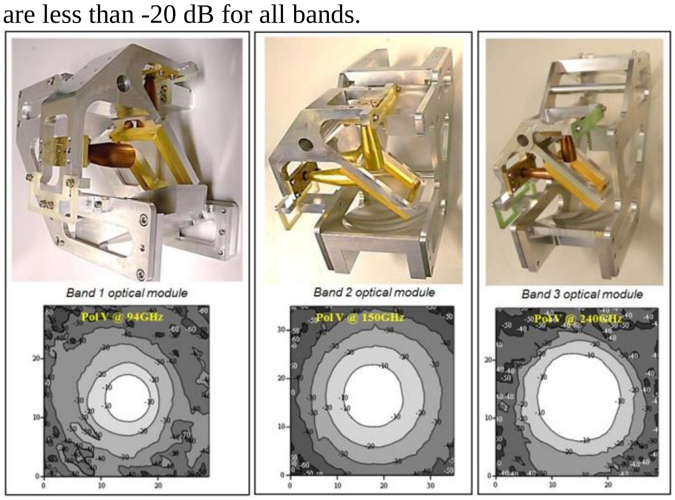

Fig. 2 Cryogenic optics modules for NOEMA Bands 1, 2 and 3 (top panels) and Pol V copolar beam patterns measured with the antenna range near the central frequency of the respective RF ranges (bottom panels).

B. Sideband Separating SIS Mixers

Fully integrated sideband separating SIS mixers have been developed for NOEMA Band 1 and 2. These mixers employ a completely planar IF coupler chip based on Nb striplines, which made it possible to integrate all components of the 2SB mixer, i.e. RF coupler, LO splitter, LO couplers, DSB mixers and IF coupler, into one E-plane splitblock as shown in Fig. 3. Band 3 will be equipped with a 2SB mixer previously developed within the European project AMSTAR+ [3, 4].
All mixers have very broadband RF and IF performance achieving ultra-low noise and a flat response across the ~8 GHz wide IF band. A detailed description of the NOEMA mixers can be found in [5].

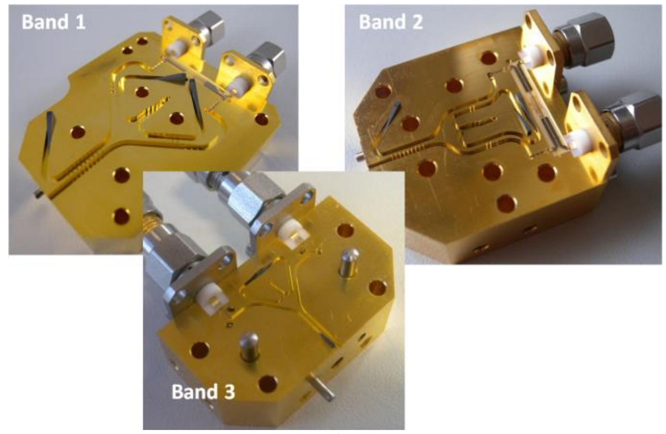

Fig. 3 Sideband separating SIS mixers for NOEMA Band 1, 2 and 3.

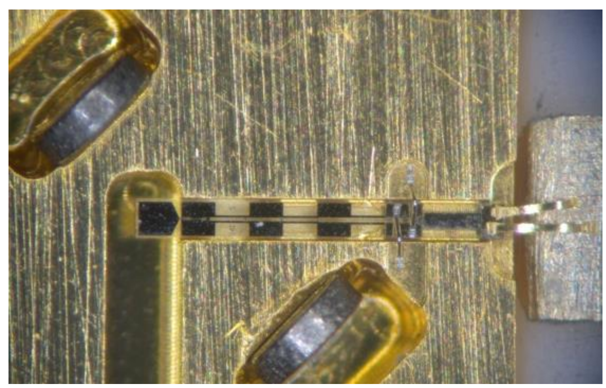

Fig. 4. Sideband Separating Mixer developed for NOEMA Band 3 (200-276 GHz) showing details of one of the two DSB mixer chips of the 2SB assembly with miniature magnets to suppress the Josephson effect.

C. Local oscillator injection scheme

A waveguide Local Oscillator injection scheme is used for the four independent RF modules. Waveguide splitters divide equally the LO power coming from the LO modules placed outside the dewar and distribute it to the two orthogonal polarization channels.

D. IF section

The NOEMA receiver outputs are four ~7.6 GHz wide IF signals, Pol H-LSB, Pol H-USB, Pol V-LSB, Pol V-USB. The NOEMA IF, 3.872-11.616 GHz, is a non-standard band and required a specific development of cryogenic LNAs and isolators (16 of each required to equip four bands of each Front-End). The isolators operate at 4 K, while the LNAs operate at 15 K. The development and production of the LNAs was subcontracted to CAY&TTI and that of the isolators to Quinstar/Pamtech.
A new room temperature IF module, connected to the NOEMA cryostat backplate, has been developed (Fig. 5). Four of such modules are used for each cryostat. Each module

selects one of the four possible IFs from each of the four RF bands. Cascaded with the IF switch are amplifiers, filters and step attenuators that deliver a final IF signal in a suitable power range.

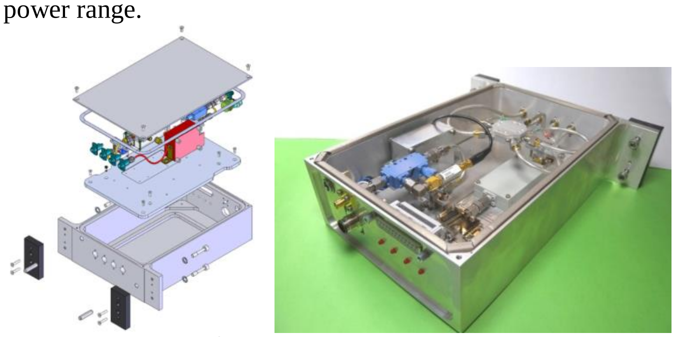

Fig. 5 Warm IF amplification module with integrated switch and digital attenuator.

E. Laser rack

A new laser rack was developed to convert the 4x~3.8-11.6 GHz IF signals from the four warm IF modules of each Front-End to optical. The signals are transported through optical fibers to the correlator. The fiber optic links are made by Miteq. Two transfer switches (or polar switches) located inside the laser rack allow changing the polarization states by reversing the signals of Pol H and Pol V. A view of the laser rack is shown in Fig. 6.

Fig. 6 NOEMA laser emitter rack.

F. EtherCAT receiver control electronics

New bias modules for the LNAs and SIS mixers, controlled by EtherCat, are under development. They will replace the old control electronics based on I^2C and CAN. One Front-End will use two bias modules to control the 16 LNAs and one single SIS junction bias module for the 8x2SB mixers (16 SIS junction chips). The warm IF and laser rack modules as well as a new cryogenic temperature monitoring system are also controlled by EtherCAT modules. Fig. 7 shows two of the modules under development. The NOEMA Front-End for Ant. 7 employs current PdBI receiver control electronics which has been adapted to the new system.

G. Calibration

For each of the four bands, the dual-polarization receiver beams can be coupled to either an ambient temperature load or a cold load thermalized inside the cryostat at 15 K. The cold load is coupled through wideband low-loss HDPE window

Fig. 7 Ethercat modules for *left*: biasing the NOEMA SIS junctions and *right*: controlling the warm IF chain and laser rack emitter.

and IR PTFE filter by pairs of mirrors located on a carousel. Two carousels are employed, one for the Band 1&2 beams, the other to the Band 3&4 beams. The two ambient temperature loads are also located on the two carousels.
An improved wideband cryogenic calibration load based on pyramidal shaped sections on Eccosorb MF-114 material from Emerson&Cuming was successfully developed.

H. Fully assembled NOEMA Front-End

A photo of the inner cryogenic parts of the fully assembled NOEMA Front-End is shown in Fig. 8. Such Front-End was installed on NOEMA Ant. 7 in December 2014 (see Fig. 9).

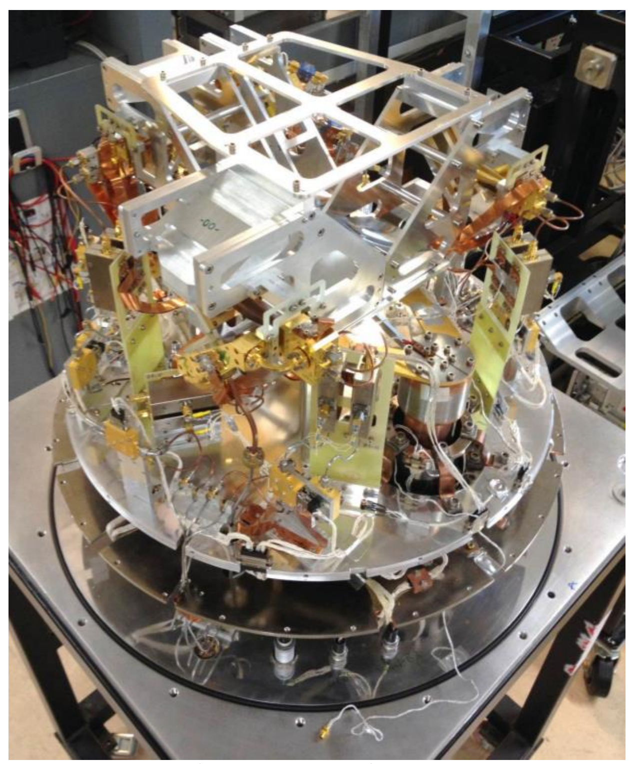

Fig. 8 View of the cold sections of the NOEMA Front-End.

III. Conclusion

We have described the main features of the mm-wave Front-End developed at IRAM for the NOEMA project. The heterodyne Front-End is based on quadri-band SIS sideband separating mixers and IF sections delivering four ~7.6 GHz wide IF outputs. The instrument features many novelties compared to the current PdBI Front-End generation. Test results of the NOEMA receivers demonstrate state-of-the-art performance and will be reported at the symposium.

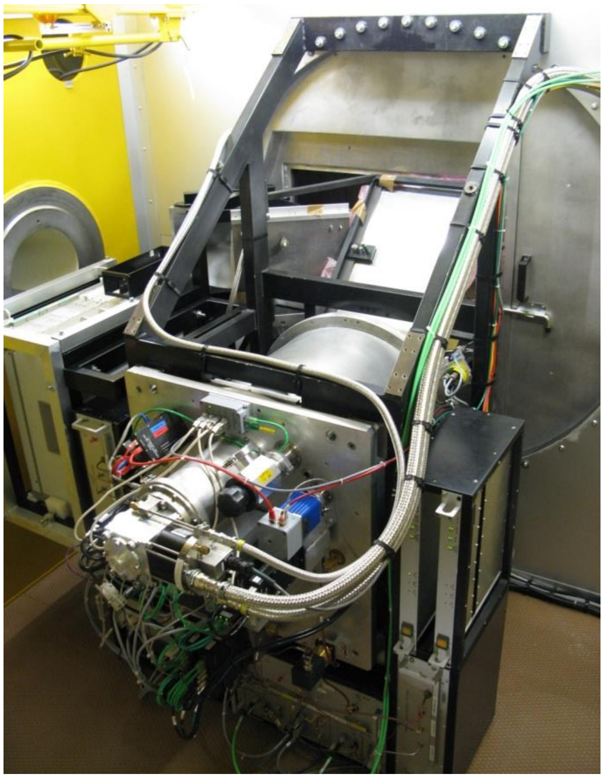

Fig. 9 View of the NOEMA Front-End installed on the Antenna 7 receiver cabin.

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